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Technical Note

The effect of the shape parameters of a sample on the hydraulic conductivity

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SUMMARY

The present study is a complement to the research investigating a laboratory method for measuring the saturated hydraulic conductivity of mountain forest soils, the results of which were presented in a paper by Ilek and Kucza (2014). The aim of the study is to analyse the influence of variation of particular cross-sections of samples and their enlarged side surface on the hydraulic conductivity measurement. The results show that a narrowing in the upper section of the sample results in an approximately twice lower disturbance of the laminar water flow than the narrowing occurring inside the sample. For that reason, the extent of the effect of the cross-section narrowing on the hydraulic conductivity measurement error is dependent on the location of the narrowing. An enlarged side surface of a sample, as described by the coefficient of side surface development, is on average 30% larger than the surface of a sample having the same volume and the same average cross-sectional area but a regular shape. The values of the coefficient of side surface development for a given sample were adopted in the range of 1.10–1.56. Among the shape parameters of the analysed irregular soil samples, the greatest impact on the measurement error is exerted by their enlarged lateral surface, which almost entirely explains the whole error of hydraulic conductivity measurement. The variability of successive cross-sectional areas of samples appears to be of marginal importance for the occurrence of this error, whose mean value was 1.15%.

1. Introduction

Hydraulic conductivity (K_{sat}) is one of the basic measures related to water flow in the ground. Among others, it depends on soil structure and texture, organic matter content and rock fragments as well as the bulk density and macroporosity of soil (Mehuys et al., 1975; Mbagwu, 1995; Sauer and Logsdon, 2002; Bagarello et al., 2004; Kodešová et al., 2006; Mao et al., 2011; Yang et al., 2013).

There are numerous methods of hydraulic conductivity testing both under field conditions and in the laboratory (e.g. Bouma and Dekker, 1981; Ohte et al., 1989; Plagge et al., 1990; Ankeny et al., 1991; Hendrayanto et al., 1998; Beckwith et al., 2003; Caldwell et al., 2005; Surridge et al., 2005; Schindler and Müller, 2006; Ilek and Kucza, 2014). Those methods are constantly developed and modified; and the choice of the best one has to optimise several interrelated factors, such as measurement precision, speed and facility as well as costs (Lee et al., 1985).

Determination of soil hydraulic conductivity under laboratory conditions requires the collection of samples with an intact structure (Twardowski and Drożdżak, 2007; Kruse et al., 2008). The laboratory method of testing the infiltration coefficient of mountain forest soils that is proposed by Ilek and Kucza (2014) is based on a novel way of soil sampling which ensures (1) preservation of the natural distribution of rock fragments, root systems and soil channels both inside the sample and on its boundary (2) preservation of the natural porosity of the soil medium, and (3) elimination of errors caused by lateral leakage. This method, consisting in formation of a soil monolith in the shape of a cylinder and filling the empty space between the monolith and the container with low-pressure foam, enables hydraulic conductivity measurement with the *ER* error of approximately 11.6% (Ilek and Kucza, 2014). This relatively small error *ER* may be eliminated by applying the so-called conversion coefficients *Wk* (Ilek and Kucza, 2014). The *ER* error originates from an irregular shape of the tested soil samples, related to the presence of rock fragments and root systems at the boundary between the soil medium and the material filling the samples. The parameters which could affect the hydraulic conductivity measurement error may include parameters characterising the variation of individual cross-sections of samples and their enlarged lateral surface. The variation of these parameters causes the processes of obstruction and increased friction of water flowing along the walls of the filling material.

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While investigating the novel method of testing of the hydraulic conductivity of mountain forest soils (Ilek and Kucza, 2014), there appeared the following question: which of the shape parameters of an irregular soil sample has a larger influence on the disturbance of flow of the water infiltrating through it, and thus on the value of error *ER*? The aim of this study is to analyse the influence of the variation of individual cross-sections of samples and their enlarged lateral surfaces on *ER* produced during hydraulic conductivity measurement.

The present study is a complement to the research investigating a laboratory method of testing the hydraulic conductivity of mountain forest soils whose results obtained for 27 soil samples were presented in the paper by Ilek and Kucza (2014). For this reason, empirical experiments on the influence of shape parameters on hydraulic conductivity were conducted after the completion of tests.

2. Materials and methods

2.1. Methodological assumptions

2.1.1. Variability of the cross-sections of samples

Taking into account the principle of continuity of water flow in a porous medium, the speed of the water flowing through a sample will undergo changes that result from differentiation of its cross-sectional areas. The adopted measure of variation of the cross-section of a given soil sample is the percentage difference between the larger cross-sectional area of the sample and its smaller cross-sectional area (its narrowing). The difference is described by the degree of narrowing *D*. Due to the location in the sample, two kinds of degree of narrowing were distinguished: (1) the degree of narrowing in the upper cross-section of the sample D_H, and (2) the degree of narrowing inside the sample D_M.

Based on an analysis of 27 foam forms, we distinguished four possibilities of occurrence of a cross-sectional narrowing of a sample, and thus four alternatives for calculating the degrees of narrowing:

1. Narrowing at the top of the sample (Fig. 1a). In this case the degree of narrowing D_H (%) was determined by the formula:

$$D_H = ((A_d - A_h)/A_d) \cdot 100 \quad (1)$$

where A_d – the lower cross-sectional area of the sample (cm^2); A_h – the area of the upmost cross-section (cm^2).

2. One narrowing in the centre of the sample (Fig. 1b). In this case the degree of narrowing D_M (%) was determined by the formula:

$$D_M = ((A_h - A_m)/A_h) \cdot 100 \quad (2)$$

where A_m – the area of the narrowing inside the sample (cm^2).

3. The narrowing at the top of the sample and one narrowing inside the sample (Fig. 1c). In this case, two degrees of narrowing had to be calculated by the formulas:

$$D_H = ((A_1 - A_h)/A_1) \cdot 100 \quad (3)$$

and

$$D_M = ((A_1 - A_m)/A_1) \cdot 100 \quad (4)$$

where A_1 – the largest cross-sectional area between the two narrowings in the sample (cm^2).

4. Two narrowings inside the sample (Fig. 1d). In this case, too, it was necessary to calculate two degrees of narrowing, according to the following formulas:

$$D_{M1} = ((A_h - A_{m1})/A_h) \cdot 100 \quad (5)$$

and

$$D_{M2} = ((A_1 - A_{m2})/A_1) \cdot 100 \quad (6)$$

where A_{m1} and A_{m2} are, respectively, the first and the second narrowing area inside the sample (cm^2).

2.1.2. The side surface of a sample

The irregular shape of soil samples obtained according to the method described by Ilek and Kucza (2014), which is largely related to the presence of the rock fragments at the boundary of the tested soil medium, will cause an increase in the side surface of the samples, which may affect hydraulic conductivity measurement. Calculation of the differentiation of the side surface of samples required the assumption that two samples, one in the shape of a regular cylinder and the other irregularly shaped, with the same volume and the same average cross-sectional area *A* and *A′*, differ from each other in the average lengths of circumference line *G* and *G′* (Fig. 2).

Accordingly, the adopted measure of variation of the boundary surface of the samples was the coefficient of side surface development C_d, calculated according to the formula:

$$C_d = G'/G \quad (7)$$

where *G′* is the length of the average circumferential line of the cross-section of an irregular sample (cm^2); *G* is the length of the circumferential line of a regularly shaped sample (cm^2).

Assuming that the side surfaces of the tested samples were perfectly smooth and even, the coefficient C_d would have a value of 1.0. However, the more varied the lateral surface, the higher the value of C_d.

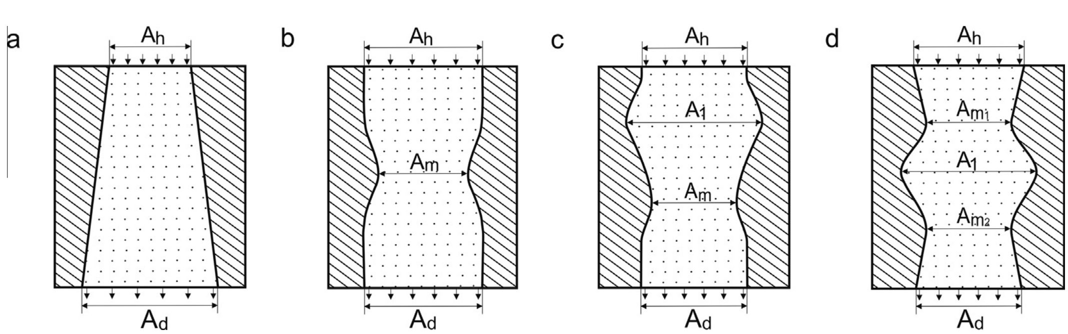

Fig. 1. Examples of the possible occurrence of narrowings in samples with an irregular shape, where (a) a sample with a narrowing of the upper cross-section, (b) a sample one internal narrowing, (c) a sample an upper narrowing and a single internal narrowing, and (d) a sample with two internal narrowings, A_h – the area of the upper cross-section, A_d – the area of the lower cross-section, A_m – the area of the internal narrowing, A_{m1} and A_{m2} – the areas of subsequent internal narrowings in a sample, A_1 – the largest area between two narrowings.